

**The Net Exchange Between Terrestrial Ecosystems and the Atmosphere
as a Result of Changes in Land Use**

Grant # NAGW-4748

**Progress Report
for the period July 1995 - March 1995**

INTERIM
711-45-02
0017
44033

to

**National Aeronautics and Space Administration
Washington, D.C.**

from

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The general purpose of this research is to improve and update (to 1990) estimates of the net flux of carbon between the world's terrestrial ecosystems and the atmosphere that results from changes in land use (e.g., deforestation and reforestation). The estimates are important for understanding the global carbon cycle, and for predicting future concentrations of atmospheric CO₂ that will result from emissions.

The emphasis of this year's research has been on northern temperate zone and boreal forests, where the greatest discrepancy exists between estimates of flux. Work is underway to improve estimates of carbon flux for North America between 1800 and 1990. Improvements will result from consideration of a greater number of ecosystems, from including fires, and from greater geographic detail. Initial estimates for North America lumped the United States and Canada together. Current work is generating specific estimates of flux for each country. The work will result in at least one manuscript submitted to a peer-reviewed journal later this year.

Other results are already in press (R.A. Houghton, "Terrestrial sources and sinks of carbon inferred from terrestrial data", *Tellus*). The findings of this analysis are described briefly here:

Two approaches have been used to calculate changes in terrestrial carbon storage with data obtained from terrestrial ecosystems, rather than with atmospheric or oceanographic data. One approach is based on the changes in carbon that result from

changes in land use (the type of work supported by this grant). The other approach is based on data from forest inventories, which should include the effects of land-use change as well as other effects from natural disturbances and environmental changes. If a significant fraction of the missing carbon sink is to be found in mid-latitude forests (as geochemical analyses suggest), one would expect direct measurement of biomass (forest inventories) to show greater accumulations of carbon than analyses in which calculated accumulations result only from regrowth following previous harvests or abandonment of agricultural land (i.e., changes in land use).

Data from Canada, the conterminous U.S., Europe, and the former U.S.S.R. show this circumstance to be correct. Accumulations of carbon in biomass and soil are 0.8 PgC yr^{-1} greater, according to analyses based on forest inventories, than expected from past management practices (land-use change).

Studies based on changes in land use (Melillo et al., 1988; Houghton, 1993; Houghton and Hackler, 1995) have found the northern temperate zone and boreal lands to be approximately balanced with respect to carbon are. Studies based on data from forest inventories (as summarized by Dixon et al., 1994) have found northern forests to be a carbon sink. The important difference between the two approaches is that analyses based on land-use change compute accumulations of carbon only as they result from deliberate human activity; that is, from forest regrowth following logging, reforestation, or abandonment of agriculture. In contrast, forest inventories measure biomass directly, and accumulations between inventories may result not only from regrowth following land management but from regrowth following previous natural disturbances or from enhanced growth due to changing environmental conditions, such as climate, nitrogen availability, and CO_2 fertilization. Data from forest inventories represent actual accumulations from all causes; calculations based on land-use change consider only the affect of previous human activity on current accumulations.

If the two approaches give similar estimates of flux, then land-use change can be assumed to account for that net flux, and other processes that affect carbon storage can be assumed to be small or compensating each other. If, as seems to be the case, data from forest inventories show greater accumulations of carbon than analyses based on land-use change, explanation and quantification of the difference may help identify the factors responsible. For example, are the differences related to geographical region? Are they related to different rates of growth, different accounting procedures for harvested products, or different rates of carbon accumulation in soils? We shall address these questions in the next year.

The finding that analyses based on forest inventories show an annual net accumulation in northern temperate zone and boreal forests that is 0.8 PgC greater than that found in analyses based on land-use change is different from earlier conclusions (Houghton 1993, 1995a, 1995b). In these earlier analyses the rate of accumulation of carbon in forests recovering from logging was shown similar to the rates of accumulation

measured by forest inventories. Because the rates were similar, we argued that land-use change accounted for the observed sink, and hence that additional carbon (missing carbon) was not likely to be found in the vegetation of these forests. These conclusions, however, were reached from a comparison of growth in biomass (gross uptake) with net accumulation in biomass. The diagrams used in this analysis that is in press helped make clear the appropriate comparisons and, hence, modified the conclusions.

If the findings are correct, the imbalance in the global carbon equation is somewhat smaller than reported in the IPCC 1994 scientific assessment (Schimel et al., 1995); that is, 1.1 rather than 1.4 PgC yr⁻¹. The difference is within the estimated error. However, the residual imbalance of 1.1 PgC yr⁻¹ for the 1980s seems unlikely to be explained by the accumulations of carbon in forests of the northern mid-latitudes, unless the forest inventories have systematically underestimated growth in one or more of the pools.

From another perspective, one in which the global carbon imbalance is defined on the basis of emissions from land-use change alone (1.6 PgC yr⁻¹), the accumulation observed in forest inventories accounts for about half of that imbalance.

The difference of 0.8 PgC yr⁻¹ between the two types of analyses suggests that processes other than land-use change are important in accumulating carbon in these mid-latitude forests. An additional amount of carbon might be accumulating either in terrestrial ecosystems that are not affected by land-use change, or in disturbed ecosystems that are not adequately understood; that is, in ecosystems that are recovering from human disturbance more rapidly than expected. The possibility remains that tropical forests, where inventories are almost non-existent, might also be accumulating carbon more rapidly than expected on the basis of land-use change. The recent measurement of a net uptake of CO₂ in an undisturbed tropical forest in the Amazon supports this possibility (Grace et al., 1995).

In the tropics, however, estimates of flux based on different methods are difficult to interpret. The total net flux of carbon from changes in land use in the tropics (1.6 PgC yr⁻¹) is consistent with recent estimates of flux based on atmospheric data (1.7 PgC) (Ciais et al. 1995). However, the geographic distribution of the flux is very different. Tropical deforestation (and hence carbon flux) is approximately evenly distributed north and south of the equator. In contrast, the recent analysis by Ciais et al. (1995) found that the northern tropics were a source of carbon and the southern tropics, a sink. Interannual differences in temperature and moisture are probably the cause of the discrepancy, as the results of Ciais et al. pertained to a single year only (1992).